

# Low and High Angular Momentum Accretion Flows in BHs: Case Study of XTE J1550–564

Roberto Soria, Kinwah Wu <sup>a</sup>, Diana Hannikainen <sup>b</sup>, Mike McCollough <sup>c</sup>, Richard Hunstead <sup>d</sup>

<sup>a</sup>Mullard Space Science Laboratory, UCL, Holmbury St. Mary, Dorking, RH5 6NT, UK.

<sup>b</sup>Department of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK.

<sup>c</sup>SD50, NASA-MSFC, Huntsville, AL 35812, USA.

<sup>d</sup>School of Physics, University of Sydney, NSW 2006, Australia

The 1998 outburst of XTE J1550–564 started with a hard X-ray spike, rising in less than a day and declining after 3–4 days; at the same time, the soft X-ray flux was rising with a longer timescale ( $\sim 10$  days). We suggest that the soft and the initial hard X-ray emission are produced by two different components of the accretion flow: a higher angular momentum flow, which forms the disk, and a lower angular momentum flow feeding the hot inner region. Thus, we argue that the onset of the outburst is determined by an increased mass transfer rate from the companion star, but the outburst morphology is also determined by the distribution of specific angular momentum in the accreting matter. In XTE J1550–564, we attribute the initial, impulsive low angular momentum accretion to the breaking down of magnetic confinement by the magnetically active secondary star. We show that a hard X-ray spike is seen at the onset of an outburst in other BHs.

## 1. Introduction

The BH soft X-ray transient XTE J1550–564 was discovered on MJD 51063 (1998 Sep 7) by the ASM on board *RXTE* [1] and by BATSE on board *CGRO* [2]. The optical counterpart was identified shortly afterwards [3], and a radio source was found at the optical position on MJD 51065 [4], with the Molonglo Observatory Synthesis Telescope (MOST), at 843MHz. From the optical ellipsoidal modulations, an orbital period of  $1.541 \pm 0.009$  d was inferred [5].

We used BATSE to monitor the hard X-ray emission (20–100 keV) from XTE J1550–564, from the start of the 1998 Sep outburst until *CGRO*'s re-entry (2000 Jun). We plot the BATSE and ASM fluxes in Fig. 1, together with the ASM hardness ratios. Details of the technique used to obtain a daily lightcurve are given in [6]. We also followed the radio source with MOST for the first 27 days after the initial detection. For a preliminary analysis of our radio data, see [6, 7, 8].

## 2. Phenomenology of the outburst

Remarkable features of the 1998 outburst are:

- *an initial impulsive rise in the hard X-rays* (Fig. 2). The BATSE (20–100 keV)

flux reached about  $0.3 \text{ ph cm}^{-2}\text{s}^{-1}$  within one day, peaking at about  $0.4 \text{ ph cm}^{-2}\text{s}^{-1}$  the next day. From *RXTE*/PCA+HEXTE data [9], the 20–200 keV flux peaked at  $\approx 1.7 \times 10^{37} \text{ erg s}^{-1}$ , for a distance of 2.5 kpc [10]. Assuming an efficiency  $\eta \sim 0.1$ , the total accreted mass required to account for the initial hard X-ray burst is  $\lesssim 10^{23} \text{ g}$ ;

- *a subsequent giant flare* that occurred almost simultaneously in both hard and soft X-rays about twelve days after the initial rise of the hard X-rays. The radio flare occurred at MJD  $51077.8 \pm 0.1$ ,  $\approx 1.8$  d after the X-ray peak, with the flux density reaching 380 mJy at 843 MHz. The hard and soft X-ray flux then settled on a plateau, with spectral and timing properties similar to the “very high state” identified in other BHs;
- *an exponential decay in the soft X-ray flux* after about 40 days. The same decay timescale for the soft flux is seen after the 1998, 1999 and 2000 outbursts.

## 3. Origin of the hard X-rays

Hard X-ray emission is not thermal emission from an accretion disk (whose maximum temper-

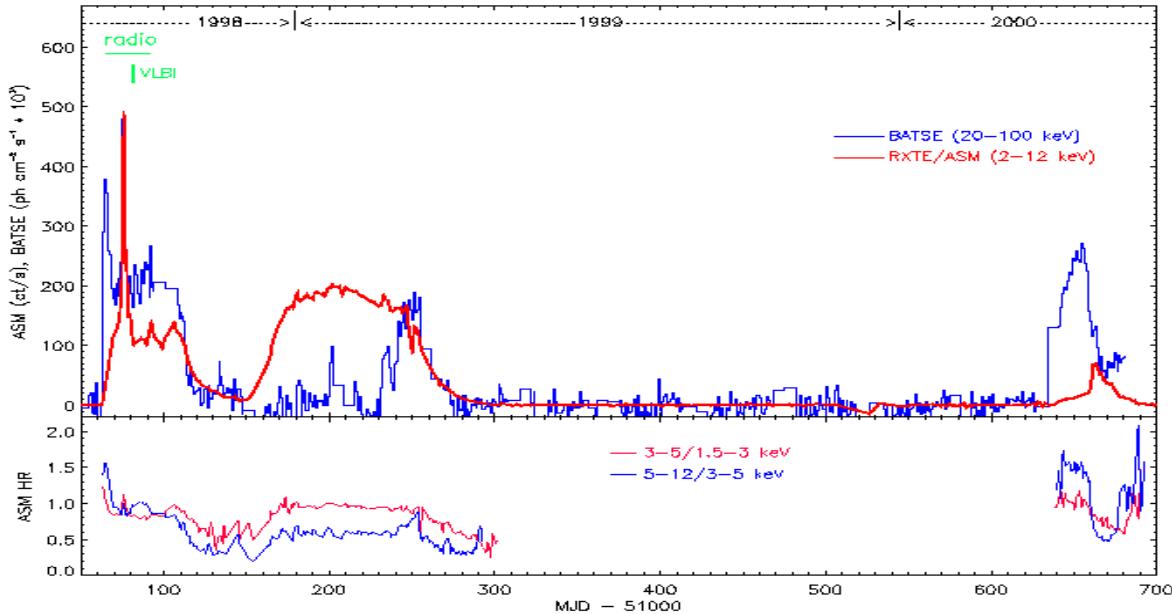


Figure 1. Top panel: BATSE (20–100 keV) and ASM (2–12 keV) fluxes from 1998 Sep to 2000 Jun. Bottom panel: ASM hardness ratios for the same period.

ature is  $\sim 1$  keV), but is produced by inverse Compton scattering of softer photons off highly energetic ( $E \sim 100$  keV) electrons near the BH. Different models have been proposed to explain the source and location of the hot electrons.

- Accretion of matter with low angular momentum can produce hard X-rays [ 11, 12, 13]. The physical justification is that free-falling electrons in a quasi-spherical inflow can acquire kinetic energies  $\gtrsim 100$  keV as they approach the BH horizon, before reaching their circularisation radius. The kinetic energy of the infalling electrons powers the Comptonisation process, either directly (bulk-motion Comptonisation) or after it has been converted into thermal energy (thermal Comptonisation).
- Alternatively, a hot, optically thin, quasi-spherical flow may already exist at small radii before the onset of the outburst (ADAF solutions; [ 14, 15]). The ADAF model may explain residual hard X-ray emission seen in some BHCs in quiescence.
- Other physical mechanisms for the produc-

tion and storing of the Comptonising electrons (eg, a magnetically heated corona on top of the disk) may be present at later stages of the outburst, and may explain the hard X-ray emission in the plateau phase (MJD 51080 – 51100). But it is unlikely that they could operate at the onset of the outburst, before a disk was fully formed.

#### 4. Low angular momentum inflow

We suggest that the initial hard X-ray spike is due to impulsive accretion of matter with low specific angular momentum, over the first few days. Meanwhile, high angular momentum matter would also be accreted through normal Roche lobe (RL) overflow. *The outburst behaviour is determined by the mass transfer rate* (which sets the energetics of the burst) *and the angular momentum distribution of the accretion flow* (which sets the initial spectral properties and the X-ray rise time).

In the ADAF scenario, the optically thin inner flow would be already present when the outburst starts, and would be responsible for the initial hard emission. The subsequent spectral softening

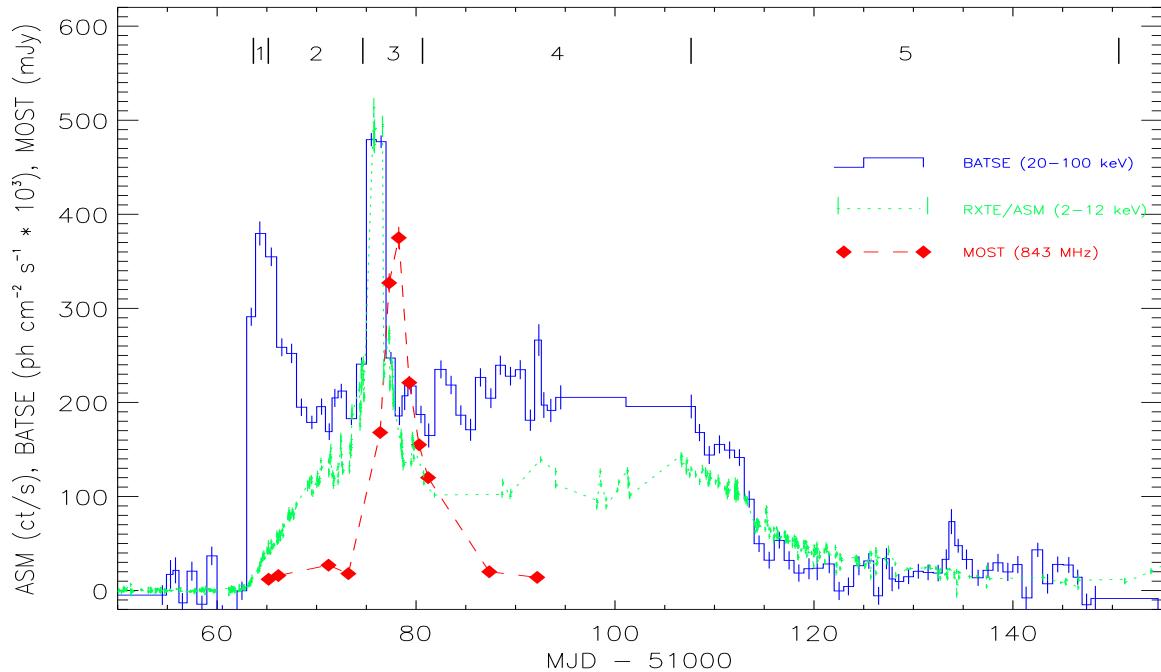


Figure 2. Hard X-ray, soft X-ray and radio lightcurves of XTE J1550–564 ; see [ 6] for details.

is attributed to the collapse of the ADAF into an optically thick disk when the mass accretion rate increases. Only one parameter determines the morphology of the outburst in the ADAF model: the mass accretion rate.

## 5. Magnetic confinement

Wind accretion is a typical example of low angular momentum accretion flows. In fact, the X-ray spectrum of XTE J1550–564 during the initial hard phase is very similar to the spectrum of Cyg X-1 in its low/hard state, when wind accretion is thought to dominate over RL overflow [ 9]. However, the companion star in XTE J1550–564 is likely to be a K subgiant, therefore it cannot produce a wind. Is there an alternative source for the subkeplerian accretion flow?

We notice that fast-rotating K subgiant stars in binary systems tend to have a strong magnetic field. The main physical reason is that, while the tidally-deformed stellar envelope can be locked in synchronous rotation with the orbit, the degenerate stellar core may not attain perfect rotational synchronism. The differential rotation leads to dynamo action and magnetic activity.

For example, RS CVn systems are magnetic close binaries containing a G/K subgiant with

a multi-kilogauss global dipolar field [ 16, 17]. Given that the orbital period in XTE J1550–564 is even shorter, and tidal deformation of the companion is even stronger than in typical RS CVn systems, we suggest that the K subgiant companion in XTE J1550–564 is also strongly magnetic.

Extended regions of cool, optically-thin, magnetically confined material around a K star are a common feature of RS CVn systems [ 18]. We suggest that the same magnetic confinement occurs in XTE J1550–564 . In fact, the mass of the confined gas can be even higher here, because the magnetic companion star is close to filling its RL. We show in [ 6] that a mass  $> 10^{23}$  g can be stored in this “magnetic bag”, enough to account for the initial hard X-ray burst. By analogy with RS CVn systems, the confined gas in XTE J1550–564 may be located well beyond the L<sub>1</sub> point, deep into the RL of the primary, but corotating with the binary (therefore with lower angular momentum than the material accreted via RL overflow).

The start of the outburst is determined by an increased mass loss from the secondary star. Part of this matter goes through L<sub>1</sub>, is accreted with a higher specific angular momentum and is responsible for the formation of the disk. Another component is temporarily channelled into the mag-

netic bags above the companion star, until the confinement breaks down; it then falls towards the accreting primary with lower angular momentum, feeding the hot, hard X-ray emitting region.

## 6. A subclass of BHs with a hard spike

XTE J1550–564 is not the only system showing a hard X-ray spike at the onset of an outburst. XTE J1859+226 [19, 20] and XTE J2012+381 [21] are two other good examples. In these three systems, the hard X-ray flux reached a maximum within the first day after detection, and then declined after about 4 days. The soft X-ray flux increased more steadily and at a slower pace, for  $\sim 10$  days. The similarity in their X-ray spectral properties can be seen from their hardness-ratio plots (Fig. 3). There is probably a subclass of BH transients, sharing a similar physical mechanism that gives rise to a strong hard X-ray spike at the onset of an outburst. A more detailed analysis of the hard X-ray properties of this type of systems will be presented elsewhere.

## 7. Conclusions

We discuss evidence of a distribution of angular momenta in the accretion flow onto the BH transient XTE J1550–564. We argue that the initial hard X-ray burst is due to a subkeplerian component, while matter accreted through the Roche lobe is responsible for the formation of a disk. We propose that the companion star is magnetically active, and its magnetic field creates a “bag” capable of confining  $\sim 10^{23}$  g of gas inside the Roche lobe of the primary, corotating with the binary. When the confinement breaks down, this low angular momentum gas reaches the inner region near the BH horizon on a free-fall timescale. We suggest that the onset of the outburst is determined by an increased mass transfer rate from the companion star, but the outburst morphology is determined by the distribution of specific angular momentum in the accreting matter.

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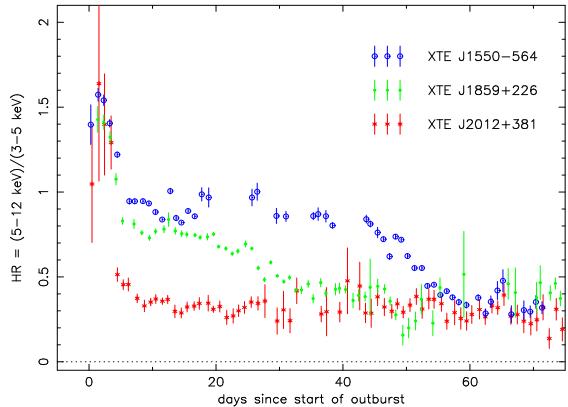


Figure 3. Evolution of the *RXTE*/ASM hardness ratios (5–12 / 3–5 keV band) during recent outbursts of the BHs XTE J1550–564 (open circles), XTE J1859+226 (filled circles) and XTE J2012+381 (asterisks). See [6] for details.